BIOHYDROGEN PRODUCTION FROM PALM OIL MILL EFFLUENT VIA SEQUENTIAL DARK-PHOTO FERMENTATION

PURANJAN MISHRA

Doctor of Philosophy

UNIVERSITI MALAYSIA PAHANG

SUPERVISOR’S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Doctor of Philosophy.

____

(Supervisor’s Signature)

Full Name : PROFESSOR DATO’ DR. ZULARISAM AB WAHID

Position : PROFESSOR

Date : 16/07/2018

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

____

(Student's Signature)

Full Name : PURANJAN MISHRA

ID Number : PPT14018

Date : JULY 2018

BIOHYDROGEN PRODUCTION FROM PALM OIL MILL EFFLUENT VIA SEQUENTIAL DARK -PHOTO FERMENTATION

PURANJAN MISHRA

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Doctor of Philosophy

Faculty of Engineering &Technology

UNIVERSITI MALAYSIA PAHANG

JULY 2018

DEDICATION

"Specially dedicated to my beloved grandfather Late Shri Gangadhar Mishra, my parents and my lovable sisters Priyanka and Monika Mishra, who constantly encouraged supported me all the way since the beginning of the studies".

ACKNOWLEDGEMENTS

My humble thanks to Almighty to pursue the study period with good health, concentration and dedication resulting in the research completion and thesis writing. I am grateful and would like to express my sincere gratitude to my supervisor, Professor Dato’ Dr. Zularisam bin Ab. Wahid for his germinal ideas, invaluable guidance, continuous encouragement and constant support to execute my research plan in proper direction. He has always impressed me with his outstanding professional conduct, his strong conviction for engineering, technology and science. I appreciate his consistent support from the first day I applied to graduate program till these concluding moments. I am truly grateful for his progressive vision during my training, his tolerance of my naïve mistake, and his commitment to my future career. I also sincerely thanks for the time spent proofreading and correcting my many mistakes. I am very lucky to have him as my supervisor and believe that he is the best motivational supervisor in the world, indeed.

I would like to express my sincere thanks, gratitude and loyalty from the very bottom of my heart to Dr. Lakhveer Singh Thakur and Dr. Sveta Thakur. From the very beginning of my research they have guided me in proper channel by providing their valuable ideas, suggestions, and advices during my tough times. Feeling very lucky and thankful to God to have such a wonderful co-supervision. I am feeling blissfulness to acknowledge the guidance, valuable suggestions constructive criticism provided by Dr. Ayodele Bamidele Victor, Dr. Nurul Islam, Dr. Santhana Krishnan, Bincy Lathakumary Vijayan and Mr. Amirul Islam. Their scientific excitement inspired me in various important moments of making right decisions, had significantly contributed to this thesis. Thank you for trusting me.

I acknowledge my sincere indebtedness and gratitude to my research lab mates and colleague Dr. Rini jaryal, Dr Ravinder Verma, Ms. Supriyanka Rana, Ms. Ain, Ms. Maria, Postgrad roommates, staff members of Faculty of Engineering Technology, UMP, all the members of Indian community in UMP. Finally my sincere gratitude to staff members of Institute of Postgraduate Studies (IPS) and International Office (IO), they are really genuine and very cooperative in nature which made me to stay at UMP pleasant and unforgettable. Thank you UMP!!!!!!!! Thank you Malaysia!!!!!!! “Satu Malaysia”.

ABSTRAK

Penghasilan hidrogen secara fermentasi daripada biomass (iaitu produk yang terhasil memalui fotosintesis) menjanjikan peluang ke arah penghasilan tenaga yang lestari. Konsep baru berbekalkan dua peringkat penembusan gelap dan fotografi (TSDPF) telah dicadangkan untuk meningkatkan penghasilan hydrogen (H_2) dan $COD_{removal}$ menggunakan efluen minyak kelapa sawit (POME) dari kilang sebagai substrat bagi proses fermentasi dalam kajian ini. Objektif utama kajian ini adalah penghasilan H2 dari POME menggunakan sistem TSDPF melalui penghasilan secara berkelompok. Pada permulaan kajian, pengasingan bakteria dari POME telah dilakukan bagi memperoleh bakteria penghasil H_2 yang dinamakan '*Bacillus* strain PUNAJAN1'. Melalu beberapa data analysis parameter fiziko-kimia yang dicadangkan dalam kajian ini, parameter optimum yang diperoleh adalah pada suhu 35°C, pH 6.5, 1.2 g L^{-1} NH_4Cl (sebagai sumber nitrogen) dan 10 g L^{-1} mannose (sebagai sumber karbon) untuk pengeluaran bio-H_2 maksimum sebanyak 2.42 mol H_2 / mol heksosa. Disamping itu, bacteria PUNAJANI juga menunjukkan penghasilan H_2 yang berkesan pada 0.23 L-H_2/g-CODremoved apabila POME diguanakn sebagai sumber karbon. Selain itu, nanopartikel nikel dan kobalt oksida yang dihasilkan secara 'hidrothermal' telah ditambah kepada POME dengan julat 0.25 hingga 3.0 mg L^{-1} POME. Keputusan menunjukkan bahawa POME dengan penambahan 1.5 mg L^{-1} NiO NPs dan 1.0 mg L^{-1} CoO NPs mempunyai ciri-ciri sebagai pemangkin dan ianya dapat meningkatkan hasil H_2 sebanyak 1.51 dan 1.67 kali ganda, jika dibandingkan dengan kawalan. Tambahan pula, kajian parameter terhadap pengoptimuman foto-fermentasi H_2 dari POME gelap (DPOME) telah dijalankan menggunakan metodologi statistic pengeluaran Box-Behnken. Hasil eksperimen tindak balas Box-Behnken terhadap permukaan telah menunjukkan kesan positif diantara pembolehubah bersandar (seperti kebegantungan pencairan DPOME, pH awal dan rejim agitasi) terhadap pengeluaran foto-H_2. Hasil maksimum H_2 yang diperoleh adalah pada keadaan optimum 40% pencairan DPOME, pH awal 6.0 dan kadar pengadukan sebanyak 140 rev/min. Melalui penggunaan strategi pengoptimuman ini, peningkatan hasil H_2 yang ketara dari 0.79 hingga 3.11 telah dicapai. Peningkatan pengeluaran H_2 dari DPOME di bawah keadaan optimum telah mencapai peningkatan hampir lima kali ganda. Akhirnya, kebarangkalian sistem TSDPF telah berjaya dilaksanakan menggunakan POME sebagai substrat. Penapaian tahap pertama dilakukan dengan menggunakan PUNAJAN1 yang terisolasi mempunyai hasil H_2 maksimum 37.11 mlH_2/g-COD dan 41% CODremoval. Lebih 40% dicairkan DPOME dengan air paip yang disterilkan untuk kegunaan fermentasi tahap kedua (foto-penapaian). Hasil keseluruhan H_2 dari sistem TSDPF meningkat dari 37.11 sehingga ke 130.89 ml H_2/g-COD, sementara peratusan $COD_{removal}$ secara serentak meningkat dari 41 hingga 93%. Peningkatan pengeluaran H_2 ini lebih tinggi daripada fermentasi POME gelap berperingkat tunggal. Hasil ini memberi kesimpulan terhadap keberkesanan penggunaan POME fermentasi gelap ke arah pengeluaran H_2 yang maksimum dan juga pengurangan kepekatan COD.

ABSTRACT

Fermentative hydrogen production using biomass (a product of photosynthesis) is a promising route toward the sustainable bioenergy production. A novel concept of two stage-sequential dark-photo fermentation (TSDPF) system was proposed for enhanced biohydrogen production and $COD_{removal}$ using palm oil mill effluent (POME) as fermentative substrate. The main objective of this study comprises the hydrogen production in batch mode from POME using TSDPF system. In the initial stage of the study, isolation of an indigenous hydrogen producing strain, '*Bacillus* strain PUNAJAN1' was done using POME sludge. The analytical data of various physicochemical parameters indicated the maximum biohydrogen production of 2.42 mol H_2/mol hexose at optimal temperature of 35°C, pH 6.5, 1.2 g L^{-1} of NH_4Cl (as a nitrogen source) and 10 g L^{-1} of mannose (as carbon source). Besides, the strain PUNAJAN1 has also shown the efficient hydrogen production ability of 0.23 L-H_2/g-$COD_{removed}$, when POME was subjected as a carbon source. Further, hydrothermally prepared nickel (NiO NPs) and cobalt oxide nanoparticles (CoO NPs) were added to POME with the range of 0.25 to 3.0 mg L^{-1} POME. Results demonstrated 1.51 and 1.67 folds of noticeable enhancement in biohydrogen production from POME supplemented with 1.5 mg L^{-1} NiO NPs and 1.0 mg L-1 CoO NPs respectively, in comparison to the control. Furthermore, a statistical approach to optimize the production of photo-fermentative H_2 from dark fermented POME using Box–Behnken response surface methodology. Experimental data has shown a positive correlation between interdependence among various parameters (such as dilution of DPOME, initial pH and agitation regime) with improved photo-H_2 production, as significant enhancement of hydrogen yield from 0.79 to 3.11 mol-H_2/mol-acetate was observed under the optimal condition of 40% of dilution of DPOME; pH 6.0; and agitation rate of 140 rev/min. The observed enhancement in photohydrogen production from DPOME under optimized conditions was almost fivefold. Finally, feasibility of TSDPF system in enhancing photo-H_2 production using POME has been successfully validated, where first stage fermentation was carried out using PUNAJAN1 strain (resulted 41% of $COD_{removal}$ along with hydrogen yield of 37.11 ml H_2/g-COD) followed by second stage fermentation using 40% diluted DPOME with sterilized tap water (photo-fermentation). Applicability of using TSDPF system in increasing hydrogen yield (from 37.11 to 130.89 ml H_2/g-COD) and $COD_{removal}$ rate (from 41 to 93%) has been implicated in this study which is reportedly far superior to single stage dark fermentation of POME. So, these results confirmed an effectual utilization of sequential dark-photo fermentation using dark POME can result in substantial hydrogen production and $COD_{removal}$.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

$H_{(Ac)}$	ACETIC ACID
$H_{(Bu)}$	Butyric acid
$H_{(Pr)}$	Propionic acid
$FeCl_2$	Ferric chloride
$MgSO_4$	Magnesium sulphate
NaOH	Sodium hydroxide
w/v	Weight to volume
m^3	Meter cube
min	Minute
g/L or gL-1	Gram per litre
M	Moles
nm	Nanometre
KJ	Kilo-joule
MJ	Mega joule
H_2	Hydrogen
L-H_2/g-	Litre hydrogen per gram of cod removal
g-CODL-1	Gram COD per litre
CFU/ml	Colony forming unit per millilitre
W/m^2	Watt per meter square
EtOH	Ethanol
ºC	Degree Celsius
$COD_{removed}$	COD removal from substrate

LIST OF ABBREVIATIONS

AD	Anaerobic Digestion
BLAST	Basic local alignment search tool
BOD	Biochemical oxygen demand
CCD	Central composite design
COD	Chemical oxygen demand
CSTR	Continuous stirrer tank reactor
DNA	Deoxyribonucleic acid
DPOME	Dark fermented palm oil mill effluent
DO	Dissolved oxygen
DoE	Design of experiment
EIA	Energy information administration
H2	Hydrogen
HPP	Hydrogen production potential
HPR	Hydrogen production rate
HY	Hydrogen yield
N	Normality
NPs	Nano-particles
PCR	Polymerase chain reaction
POME	Palm oil mill effluent
RSM	Response surface methodology
RSM	Response surface methodology
SD	Standard deviation
TSS	Total suspended solids
UASB	Up-flow anaerobic sludge blanket
VFA	Volatile fatty acid
VSS	Volatile suspended solids

REFERENCES

Abdelsalam, E., Samer, M., Attia, Y., Abdel-Hadi, M., Hassan, H. & Badr, Y. (2017). Effects of Co and Ni nanoparticles on biogas and methane production from anaerobic digestion of slurry. *Energ Convers Manage, 141*, 108-119.

Abdullah, S. A. & Nakagoshi, N. (2007). Forest fragmentation and its correlation to human land use change in the state of Selangor, peninsular Malaysia. *Forest Ecology and Management*, 241(1), 39-48.

Abrams, J. F., Hohn, S., Rixen, T., Baum, A. & Merico, A. (2016). The impact of Indonesian peatland degradation on downstream marine ecosystems and the global carbon cycle. *Global Change Biology*, *22*(*1*), 325-337.

Adessi, A. & De Philippis, R. (2014). Photobioreactor design and illumination systems for H 2 production with anoxygenic photosynthetic bacteria: a review. *International Journal of Hydrogen Energy*, *39*(*7*), 3127-3141.

Ahmad, A., Buang, A. & Bhat, A. (2016). Renewable and sustainable bioenergy production from microalgal co-cultivation with palm oil mill effluent (POME): a review. *Renewable and Sustainable Energy Review*s, *65*, 214-234.

Ahmad, S., Ab Kadir, M. Z. A. & Shafie, S. (2011). Current perspective of the renewable energy development in Malaysia. *Renewable and Sustainable Energy Reviews*, *15*(*2*), 897-904.

Akman, M. C., Erguder, T. H., Gündüz, U. & Eroğlu, İ. (2015). Investigation of the effects of initial substrate and biomass concentrations and light intensity on photofermentative hydrogen gas production by Response Surface Methodology. Internati*onal Journal of Hydrogen E*nergy, *40*(*15*), 5042-5049.

Alalayah, W. M., Kalil, M. S., Kadhum, A. A. H., Jahim, J. M., Jaapar, S. & Alauj, N. (2009). Bio-hydrogen production using a two-stage fermentation process. P*akistan Journal of Biological Scie*nces, *12*(*22*), 1462.

Alivisatos, P., Cummings, P., De Yoreo, J., Fichthorn, K., Gates, B., Hwang, R., . . . Michalske, T. (2004). Nanoscience Research for Energy Needs. Report of the National Nanotechnology Initiative Grand Challenge Workshop, March 16-18, 2004.

An, D., Li, Q., Wang, X., Yang, H. & Guo, L. (2014). Characterization on hydrogen production performance of a newly isolated Clostridium beijerinckii YA001 using xylose. *International Journal of hydrogen Energy*, *39*(*35*), 19928-19936.

Argun, H. & Kargi, F. (2010). Photo-fermentative hydrogen gas production from dark fermentation effluent of ground wheat solution: effects of light source and light intensity. *International Journal of Hydrogen Energy*, *35*(*4*), 1595-1603.

Argun, H. & Kargi, F. (2011). Bio-hydrogen production by different operational modes of dark and photo-fermentation: an overview. *International Journal of Hydrogen Energy*, *36*(*13*), 7443-7459.

Asada, Y., Tokumoto, M., Aihara, Y., Oku, M., Ishimi, K., Wakayama, T., . . . Kohno, H. (2006). Hydrogen production by co-cultures of Lactobacillus and a photosynthetic bacterium, Rhodobacter sphaeroides RV. *International Journal of Hydrogen Energy*, *31*(*11*), 1509-1513.

Azbar, N. & Dokgoz, F. T. C. (2010). The effect of dilution and L-malic acid addition on bio-hydrogen production with Rhodopseudomonas palustris from effluent of an acidogenic anaerobic reactor. *International Journal of Hydrogen Energy*, *35*(*10*), 5028-5033.

Aziz, M., Budianto, D. & Oda, T. (2016). Computational fluid dynamic analysis of co-firing of palm kernel shell and coal. *Energies*, *9*(*3*), 137.

Baek, Y.-W. & An, Y.-J. (2011). Microbial toxicity of metal oxide nanoparticles (CuO, NiO, ZnO, and Sb 2 O 3) to Escherichia coli, Bacillus subtilis, and Streptococcus aureus. *Science of the Total Environment*, *409*(*8*), 1603-1608.

Banos, R., Manzano-Agugliaro, F., Montoya, F., Gil, C., Alcayde, A. & Gómez, J. (2011). Optimization methods applied to renewable and sustainable energy: A review. *Renewable and Sustainable Energy Reviews*, *15*(*4*), 1753-1766.

Bao, M., Su, H. & Tan, T. (2012). Biohydrogen Production by Dark Fermentation of Starch Using Mixed Bacterial Cultures of Bacillus sp and Brevumdimonas sp. *Energy & Fuels*, *26*(*9*), 5872-5878.

Bartacek, J., Zabranska, J. & Lens, P. N. (2007). Developments and constraints in fermentative hydrogen production. *Biofuels, Bioproducts and Biorefining*, *1*(*3*), 201-214.

Basak, N. & Das, D. (2007). The prospect of purple non-sulfur (PNS) photosynthetic bacteria for hydrogen production: the present state of the art. *World Journal of Microbiology and Biotechnology*, *23*(*1*), 31-42.

Basiron, Y. (2007). Palm oil production through sustainable plantations. European *Journal of Lipid Science and Technology*, *109*(*4*), 289-295.

Battersby, A. R. & Sheng, Z.-C. (1982). Preparation and spectroscopic properties of Co III-isobacteriochlorins: relationship to the cobalt-containing proteins from Desulphovibrio gigas and D. desulphuricans. *Journal of the Chemical Society, Chemical Communications*(*24*), 1393-1394.

Benemann, J. R., Berenson, J. A., Kaplan, N. O. & Kamen, M. D. (1973). Hydrogen evolution by a chloroplast-ferredoxin-hydrogenase system. *Proceedings of the National Academy of Sciences*, *70*(*8*), 2317-2320.

Bhattacharya, M., Paramati, S. R., Ozturk, I. and Bhattacharya, S. (2016). The effect of renewable energy consumption on economic growth: Evidence from top 38 countries. *Applied Energy*, *162*, 733-741.

Bicalho, T., Bessou, C. & Pacca, S. A. (2016). Land use change within EU sustainability criteria for biofuels: The case of oil palm expansion in the Brazilian Amazon. *Renewable Energy*, *89*, 588-597.

Bini, E. (2010). Archaeal transformation of metals in the environment. *FEMS Microbiology Ecology*, *73*(*1*), 1-16.

Bisaillon, A., Turcot, J. & Hallenbeck, P. C. (2006). The effect of nutrient limitation on hydrogen production by batch cultures of Escherichia coli. *International Journal of Hydrogen Energy, 31*(*11*), 1504-1508.

Box, G. E. & Wilson, K. B. (1992). On the experimental attainment of optimum conditions Breakthroughs in Statistics (pp. 270-310): Springer.

Brentner, L. B., Peccia, J. & Zimmerman, J. B. (2010). Challenges in developing biohydrogen as a sustainable energy source: implications for a research agenda. *Environmental Science & Technology*, *44(7*), 2243-2254.

Brown, E. & Jacobson, M. (2005). Cruel oil. Center for Science in the Public Interest, Washington, DC.

Bruce, D. & Vasil'ev, S. (2004). Excess light stress: multiple dissipative processes of excess excitation. *Chlorophyll a Fluorescence*, 497-523.

Budiman, P. M., Wu, T. Y., Ramanan, R. N. & Md. Jahim, J. (2015). Improvement of biohydrogen production through combined reuses of palm oil mill effluent together with pulp and paper mill effluent in photofermentation. *Energy & Fuels*, *29*(*9*), 5816-5824.

Cai, M., Liu, J. & Wei, Y. (2004). Enhanced biohydrogen production from sewage sludge with alkaline pretreatment. *Environmental Science & Technology*, *38*(*11*), 3195-3202.

Carnes, C. L., Stipp, J., Klabunde, K. J. & Bonevich, J. (2002). Synthesis, characterization, and adsorption studies of nanocrystalline copper oxide and nickel oxide. *Langmuir*, *18*(*4*), 1352-1359.

Celli, G. B., Ghanem, A. & Brooks, M. S.-L. (2015). Optimization of ultrasound-assisted extraction of anthocyanins from haskap berries (Lonicera caerulea L.) using Response Surface Methodology. *Ultrasonics sonochemistry*, *27*, 449-455.

Chandra, R., Takeuchi, H. & Hasegawa, T. (2012). Methane production from lignocellulosic agricultural crop wastes: A review in context to second generation of biofuel production. *Renewable and Sustainable Energy Reviews*, *16*(*3*), 1462-1476.

Chang, J.-S., Lee, K.-S. & Lin, P.-J. (2002). Biohydrogen production with fixed-bed bioreactors. *International Journal of Hydrogen Energy*, *27*(*11*), 1167-1174.

Chen, C.-Y., Lu, W.-B., Liu, C.-H. & Chang, J.-S. (2008). Improved phototrophic H 2 production with Rhodopseudomonas palustris WP3-5 using acetate and butyrate as dual carbon substrates. *Bioresource Technology*, *99*(*9*), 3609-3616.

Chen, C.-Y., Yeh, K.-L., Lo, Y.-C., Wang, H.-M. & Chang, J.-S. (2010). Engineering strategies for the enhanced photo-H 2 production using effluents of dark fermentation processes as substrate. *International Journal of Hydrogen Energy, 35*(*24*), 13356-13364.

Chen, C., Lin, C. & Chang, J. (2001). Kinetics of hydrogen production with continuous anaerobic cultures utilizing sucrose as the limiting substrate. *Applied Microbiology and Biotechnology, 57*(*1*), 56-64.

Chen, W.-M., Tseng, Z.-J., Lee, K.-S. & Chang, J.-S. (2005). Fermentative hydrogen production with Clostridium butyricum CGS5 isolated from anaerobic sewage sludge. *International Journal of Hydrogen Energy, 30*(*10*), 1063-1070.

Cheng, J., Su, H., Zhou, J., Song, W. & Cen, K. (2011a). Hydrogen production by mixed bacteria through dark and photo fermentation. *International Journal of Hydrogen Energy, 36*(*1*), 450-457.

Cheng, J., Su, H., Zhou, J., Song, W. & Cen, K. (2011b). Microwave-assisted alkali pretreatment of rice straw to promote enzymatic hydrolysis and hydrogen production in dark-and photo-fermentation. *International Journal of Hydrogen Energy, 36*(*3*), 2093-2101.

Cheong, D.-Y. & Hansen, C. L. (2006). Bacterial stress enrichment enhances anaerobic hydrogen production in cattle manure sludge. *Applied microbiology and biotechnology, 72*(*4*), 635.

Choi, J.-M., Han, S.-K., Kim, J.-T. & Lee, C.-Y. (2016). Optimization of combined (acid+ thermal) pretreatment for enhanced dark fermentative H 2 production from Chlorella vulgaris using response surface methodology. *International Biodeterioration & Biodegradation, 108*, 191-197.

Chong, M.-L., Rahim, R. A., Shirai, Y. & Hassan, M. A. (2009a). Biohydrogen production by Clostridium butyricum EB6 from palm oil mill effluent. *International Journal of Hydrogen Energy, 34*(*2*), 764-771.

Chong, M.-L., Rahim, R. A., Shirai, Y. & Hassan, M. A. (2009b). Biohydrogen production by Clostridium butyricum EB6 from palm oil mill effluent. *Int J Hydrogn Energy, 34*(*2*), 764-771.

Chookaew, T., Sompong, O. & Prasertsan, P. (2015). Biohydrogen production from crude glycerol by two stage of dark and photo fermentation. *international journal of hydrogen energy, 40*(*24*), 7433-7438.

Cleland, R. E., Rees, D. & Horton, P. (1992). Light-induced fluorescence quenching and loss of photochemistry in chromatophores of photosynthetic purple bacteria. *Journal of Photochemistry and Photobiology B: Biology, 13*(*3-4*), 253-265.

Corley, R. (2009). How much palm oil do we need? *Environmental Science & Policy, 12*(*2*), 134-139.

Corley, R. H. V. & Tinker, P. (2008). *The oil palm*. John Wiley & Sons.

Das, D. (2009). Advances in biohydrogen production processes: an approach towards commercialization. *international journal of hydrogen energy*, *34(17*), 7349-7357.

Das, D. & Veziroglu, T. N. (2008). Advances in biological hydrogen production processes. *International Journal of Hydrogen Energy*, *33*(*21*), 6046-6057.

Dasgupta, C. N., Gilbert, J. J., Lindblad, P., Heidorn, T., Borgvang, S. A., Skjanes, K. & Das, D. (2010). Recent trends on the development of photobiological processes and photobioreactors for the improvement of hydrogen production. *international journal of hydrogen energy*, *35*(*19*), 10218-10238.

de Lacey, A. L., Fernández, V. M. & Rousset, M. (2005). Native and mutant nickel–iron hydrogenases: unravelling structure and function. *Coordination chemistry reviews*, *249*(*15*), 1596-1608.

Dhiaulhaq, A., Gritten, D., De Bruyn, T., Yasmi, Y., Zazali, A. & Silalahi, M. (2014). Transforming conflict in plantations through mediation: Lessons and experiences from Sumatera, Indonesia. *Forest Policy and Economics*, *41*, 22-30.

Dinopoulou, G., Rudd, T. & Lester, J. N. (1988). Anaerobic acidogenesis of a complex wastewater: I. The influence of operational parameters on reactor performance. *Biotechnology and bioengineering*, *31*(*9*), 958-968.

Dodds, P. E., Staffell, I., Hawkes, A. D., Li, F., Grünewald, P., McDowall, W. & Ekins, P. (2015). Hydrogen and fuel cell technologies for heating: a review. i*nternational journal of hydrogen energy*, *40*(*5*), 2065-2083.

Dong, L., Zhenhong, Y., Yongming, S. & Longlong, M. (2010). Evaluation of pretreatment methods on harvesting hydrogen producing seeds from anaerobic digested organic fraction of municipal solid waste (OFMSW). *international journal of hydrogen energy*, *35*(*15*), 8234-8240.

Duangmanee, T., Padmasiri, S., Simmons, J., Raskin, L. & Sung, S. (2002). Hydrogen production by anaerobic microbial communities exposed to repeated heat treatments. *Proceedings of the Water Environment Federation*, *2002*(*16*), 823-841.

Duangmanee, T., Padmasiri, S., Simmons, J., Raskin, L. & Sung, S. (2007). Hydrogen production by anaerobic microbial communities exposed to repeated heat treatments. *Water Environment Research*, *79*(*9*), 975-983.

Elksibi, I., Haddar, W., Ticha, M. B. & Mhenni, M. F. (2014). Development and optimisation of a non conventional extraction process of natural dye from olive solid waste using response surface methodology (RSM). *Food chemistry*, *161*, 345-352.

Espinoza-Escalante, F. M., Pelayo-Ortíz, C., Navarro-Corona, J., González-García, Y., Bories, A. & Gutiérrez-Pulido, H. (2009). Anaerobic digestion of the vinasses from the fermentation of Agave tequilana Weber to tequila: the effect of pH, temperature and hydraulic retention time on the production of hydrogen and methane. *Biomass and bioenergy*, *33*(*1*), 14-20.

Esposito, G., Frunzo, L., Panico, A. & Pirozzi, F. (2012). Enhanced bio-methane production from co-digestion of different organic wastes. *Environmental technology*, *33*(*24*), 2733-2740.

Federation, W. E. & Association, A. P. H. (2005). Standard methods for the examination of water and wastewater. American Public Health Association (APHA): Washington, DC, USA.

Fermoso, F. G., Bartacek, J., Jansen, S. & Lens, P. N. (2009). Metal supplementation to UASB bioreactors: from cell-metal interactions to full-scale application. *Science of the Total Environment*, *407*(*12*), 3652-3667.

Ferreira, S. C., Bruns, R., Ferreira, H., Matos, G., David, J., Brandao, G., Souza, A. (2007). Box-Behnken design: an alternative for the optimization of analytical methods. *Analytica chimica acta*, *597*(*2*), 179-186.

Fontecilla-Camps, J. C. (1996). The active site of Ni-Fe hydrogenases: model chemistry & crystallographic results. *JBIC Journal of Biological Inorganic Chemistry, 1(2*), 91-98.

Fuchs, G. (1986). CO2 fixation in acetogenic bacteria: variations on a theme. *FEMS Microbiology Letters*, *39*(*3*), 181-213.

Gaffron, H. & Rubin, J. (1942). Fermentative and photochemical production of hydrogen in algae. *The Journal of General Physiology*, *26*(*2*), 219-240.

Gelegenis, J., Georgakakis, D., Angelidaki, I. & Mavris, V. (2007). Optimization of biogas production by co-digesting whey with diluted poultry manure. *Renewable energy*, *32*(*13*), 2147-2160.

Ghimire, A., Frunzo, L., Pontoni, L., d'Antonio, G., Lens, P. N., Esposito, G. & Pirozzi, F. (2015). Dark fermentation of complex waste biomass for biohydrogen production by pretreated thermophilic anaerobic digestate. *Journal of Environmental Management*, *152*, 43-48.

Guan, X., Sun, Y., Qin, H., Li, J., Lo, I. M., He, D. & Dong, H. (2015). The limitations of applying zero-valent iron technology in contaminants sequestration and the corresponding countermeasures: the development in zero-valent iron technology in the last two decades (1994–2014). *water research*, *75*, 224-248.

Guo, L., Li, X.-M., Bo, X., Yang, Q., Zeng, G.-M., Liao, D.-x. & Liu, J.-J. (2008). Impacts of sterilization, microwave and ultrasonication pretreatment on hydrogen producing using waste sludge. *Bioresource technology*, *99*(*9*), 3651-3658.

Guo, W.-Q., Ren, N.-Q., Wang, X.-J., Xiang, W.-S., Ding, J., You, Y. & Liu, B.-F. (2009). Optimization of culture conditions for hydrogen production by Ethanoligenens harbinense B49 using response surface methodology. *Bioresource technology*, *100*(*3*), 1192-1196.

Guo, X. M., Trably, E., Latrille, E., Carrere, H. & Steyer, J.-P. (2010). Hydrogen production from agricultural waste by dark fermentation: a review. *international journal of hydrogen energy*, *35*(*19*), 10660-10673.

Gustavsson, J., Yekta, S. S., Sundberg, C., Karlsson, A., Ejlertsson, J., Skyllberg, U. & Svensson, B. H. (2013). Bioavailability of cobalt and nickel during anaerobic digestion of sulfur-rich stillage for biogas formation. *Applied energy*, *112*, 473-477.

Hallenbeck, P. C. (2009). Fermentative hydrogen production: principles, progress, and prognosis. *International Journal of Hydrogen Energy*, *34*(*17*), 7379-7389.

Hallenbeck, P. C. (2014). Bioenergy from microorganisms: an overview Microbial BioEnergy: *Hydrogen Production* (pp. 3-21): Springer.

Hallenbeck, P. C. & Benemann, J. R. (2002). Biological hydrogen production; fundamentals and limiting processes. *international journal of hydrogen energy, 27*(*11*), 1185-1193.

Halpern, J. (1985). Mechanisms of coenzyme B12-dependent rearrangements. *Science, 227*, 869-876.

Hamdi, M. (1991). Effects of agitation and pretreatment on the batch anaerobic digestion of olive mil. *Bioresource technology*, *36*(*2*), 173-178.

Hamed, E. & Sakr, A. (2001). Application of multiple response optimization technique to extended release formulations design. *Journal of controlled release*, *73*(*2*), 329-338.

Hamilton, R. L., Trimmer, M., Bradley, C. & Pinay, G. (2016). Deforestation for oil palm alters the fundamental balance of the soil N cycle. *Soil Biology and Biochemistry*, *95*, 223-232.

Han, H., Cui, M., Wei, L., Yang, H. & Shen, J. (2011). Enhancement effect of hematite nanoparticles on fermentative hydrogen production. *Bioresource Technology*, *102*(*17*), 7903-7909.

Hansen, S. (2007). Feasibility study of performing an life cycle assessment on crude palm oil production in Malaysia (9 pp). *The International Journal of Life Cycle Assessment*, *12*(*1*), 50-58.

Hawkes, F., Dinsdale, R., Hawkes, D. & Hussy, I. (2002a). Sustainable fermentative hydrogen production: challenges for process optimisation. *Int J Hydrogen Energy*, *27*(*11*), 1339-1347.

Hawkes, F., Dinsdale, R., Hawkes, D. e. & Hussy, I. (2002b). Sustainable fermentative hydrogen production: challenges for process optimisation. *international journal of hydrogen energy*, *27*(*11-12*), 1339-1347.

He, Z. & Angenent, L. T. (2006). Application of bacterial biocathodes in microbial fuel cells. *Electroanalysis*, *18*(*19‐ 20*), 2009-2015.

Hellingwerf, K., Crielaard, W., Hoff, W., Matthijs, H., Mur, L. & Van Rotterdam, B. (1994). Photobiology of bacteria. Antonie van Leeuwenhoek, 65(4), 331-347.

Hiligsmann, S., Beckers, L., Masset, J., Hamilton, C. & Thonart, P. (2014). Improvement of fermentative biohydrogen production by Clostridium butyricum CWBI1009 in sequenced-batch, horizontal fixed bed and biodisc-like anaerobic reactors with biomass retention. *international journal of hydrogen energy, 39*(*13*), 6899-6911.

Hinkelmann, K. (2011). *Design and analysis of experiments, special designs and applications*. John Wiley & Sons.

Imhoff, J. F., Hiraishi, A. & Süling, J. (2005). Anoxygenic phototrophic purple bacteria Bergey's Manual® of Systematic Bacteriology (pp. 119-132): Springer.

Inubushi, K., Furukawa, Y., Hadi, A., Purnomo, E. & Tsuruta, H. (2003). Seasonal changes of CO 2, CH 4 and N 2 O fluxes in relation to land-use change in tropical peatlands located in coastal area of South Kalimantan. *Chemosphere*, *52(3*), 603-608.

Jackson, D. & Ellms, J. (1896). On odors and tastes of surface waters with special reference to Anabaena, a microscopical organism found in certain water supplies of Massachusetts. *Rep. Mass. State Board Health*, *1896*, 410-420.

Jiménez, J., Guardia-Puebla, Y., Romero-Romero, O., Cisneros-Ortiz, M., Guerra, G., Morgan-Sagastume, J. & Noyola, A. (2014). Methanogenic activity optimization using the response surface methodology, during the anaerobic co-digestion of agriculture and industrial wastes. Microbial community diversity. *Biomass and bioenergy*, *71*, 84-97.

Kalia, V., Jain, S., Kumar, A. & Joshi, A. (1994). Frementation of biowaste to H2 by Bacillus licheniformis. *World Journal of Microbiology and Biotechnology*, *10*(*2*), 224-227.

Kapdan, I. K. & Kargi, F. (2006). Bio-hydrogen production from waste materials. *Enzyme and microbial technology*, *38*(*5*), 569-582.

Karim, K., Hoffmann, R., Klasson, K. T. & Al-Dahhan, M. (2005). Anaerobic digestion of animal waste: *Effect of mode of mixing. water research*, *39*(*15*), 3597-3606.

Karray, R., Hamza, M. & Sayadi, S. (2015). Evaluation of ultrasonic, acid, thermo-alkaline and enzymatic pre-treatments on anaerobic digestion of Ulva rigida for biogas production. *Bioresource technology*, *187*, 205-213.

Khajeh, M. (2011). Response surface modelling of lead pre-concentration from food samples by miniaturised homogenous liquid–liquid solvent extraction: Box–Behnken design. *Food chemistry*, *129(4*), 1832-1838.

Khan, Z., Yusup, S., Ahmad, M. M., Chok, V. S., Uemura, Y. & Sabil, K. M. (2010). Review on hydrogen production technologies in Malaysia. *International Journal of Engineering & Technology*, *10*(*2*).

Khanal, S. K., Chen, W.-H., Li, L. & Sung, S. (2004). Biological hydrogen production: effects of pH and intermediate products. i*nternational journal of hydrogen energy*, *29*(*11*), 1123-1131.

Kim, D.-H. & Kim, M.-S. (2011). Hydrogenases for biological hydrogen production. *Bioresource technology*, *102*(*18*), 8423-8431.

Klabunde, K. J. (2001). Introduction to nanotechnology. *Nanoscale Materials in Chemistry*, 1-13.

Knezevic, P., Aleksic, V., Simin, N., Svircev, E., Petrovic, A. & Mimica-Dukic, N. (2016). Antimicrobial activity of Eucalyptus camaldulensis essential oils and their interactions with conventional antimicrobial agents against multi-drug resistant Acinetobacter baumannii. *Journal of Ethnopharmacology, 178*, 125-136.

Kobayashi, M. & Shimizu, S. (1999). Cobalt proteins. *The FEBS Journal*, *261*(1), 1-9.

Krishnan, S., Singh, L., Mishra, P., Nasrullah, M., Sakinah, M., Thakur, S., Wahid, Z. A. (2017). Comparison of process stability in methane generation from palm oil mill effluent using dairy manure as inoculum. *Environmental Technology & Innovation.*

Kumar, G., Sivagurunathan, P., Sen, B., Kim, S.-H. & Lin, C.-Y. (2017). Mesophilic continuous fermentative hydrogen production from acid pretreated de-oiled jatropha waste hydrolysate using immobilized microorganisms. Bioresource technology.

Kumar, P., Sharma, R., Ray, S., Mehariya, S., Patel, S. K., Lee, J.-K. & Kalia, V. C. (2015). Dark fermentative bioconversion of glycerol to hydrogen by Bacillus thuringiensis. *Bioresource technology, 182,* 383-388.

Kyazze, G., Martinez- Perez, N., Dinsdale, R., Premier, G., Hawkes, F., Guwy, A. J. & Hawkes, D. (2006). Influence of substrate concentration on the stability and yield of continuous biohydrogen production. *Biotechnology and bioengineering, 93(5),* 971-979.

Lam, M. K. & Lee, K. T. (2011). Renewable and sustainable bioenergies production from palm oil mill effluent (POME): win–win strategies toward better environmental protection. *Biotechnology advances*, *29(1)*, 124-141.

Latif, A., Suhaimi, A. A. & Romzay, R. A. (2014). Application of Elaeis guineensis leaves in palm oil mill effluent treatment. *Indian Journal of Science and Technology, 7(3)*, 254–261.

Laurinavichene, T. V., Belokopytov, B. F., Laurinavichius, K. S., Khusnutdinova, A. N., Seibert, M. & Tsygankov, A. A. (2012). Towards the integration of dark-and photo-fermentative waste treatment. 4. Repeated batch sequential dark-and photofermentation using starch as substrate. *international journal of hydrogen energy, 37(10)*, 8800-8810.

Lay, J.-J., Lee, Y.-J. & Noike, T. (1999). Feasibility of biological hydrogen production from organic fraction of municipal solid waste. *water research, 33(11)*, 2579-2586.

Lee, K.-S., Whang, L.-M., Saratale, G. D., Chen, S.-D., Chang, J.-S., Hafez, H., .Naggar, H. (2014). Biological hydrogen production: dark fermentation. Handbook of Hydrogen Energy, 249.

Li, C. & Fang, H. H. (2007). Fermentative hydrogen production from wastewater and solid wastes by mixed cultures. Critical Reviews in Environmental *Science and Technology, 37(1),* 1-39.

Liao, X. & Li, H. (2015). Biogas production from low-organic-content sludge using a high-solids anaerobic digester with improved agitation. *Applied energy, 148*, 252-259.

Lin, C.-Y., Wu, C.-C., Wu, J.-H. & Chang, F.-Y. (2008). Effect of cultivation temperature on fermentative hydrogen production from xylose by a mixed culture. *Biomass and bioenergy*, *32*(12), 1109-1115.

Lin, R., Cheng, J., Ding, L., Song, W., Liu, M., Zhou, J. & Cen, K. (2016). Enhanced dark hydrogen fermentation by addition of ferric oxide nanoparticles using Enterobacter aerogenes. *Bioresource technology, 207*, 213-219.

Liu, B.-F., Ren, N.-Q., Xie, G.-J., Ding, J., Guo, W.-Q. & Xing, D.-F. (2010). Enhanced bio-hydrogen production by the combination of dark-and photo-fermentation in batch culture. *Bioresource technology, 101*(14), 5325-5329.

Liu, B., Jin, Y., Wang, Z., Xing, D., Ma, C., Ding, J. & Ren, N. (2017). Enhanced photo-fermentative hydrogen production of Rhodopseudomonas sp. nov. strain A7 by the addition of TiO 2, ZnO and SiC nanoparticles. *international journal of hydrogen energy.*

Liu, H. & Wang, G. (2012). Hydrogen production of a salt tolerant strain Bacillus sp. B2 from marine intertidal sludge. *World Journal of Microbiology and Biotechnology, 28(1),* 31-37.

Liu, X., Mu, T., Sun, H., Zhang, M. & Chen, J. (2013). Optimisation of aqueous two-phase extraction of anthocyanins from purple sweet potatoes by response surface methodology. Food chemistry, 141(3), 3034-3041.

Lo, Y.-C., Chen, C.-Y., Lee, C.-M. & Chang, J.-S. (2010). Sequential dark–photo fermentation and autotrophic microalgal growth for high-yield and CO 2-free biohydrogen production. *international journal of hydrogen energy, 35(20)*, 10944-10953.

Lo, Y.-C., Chen, W.-M., Hung, C.-H., Chen, S.-D. & Chang, J.-S. (2008). Dark H 2 fermentation from sucrose and xylose using H 2-producing indigenous bacteria: feasibility and kinetic studies. *water research, 42(4),* 827-842.

Logan, B. E., Call, D., Cheng, S., Hamelers, H. V., Sleutels, T. H., Jeremiasse, A. W. & Rozendal, R. A. (2008). Microbial electrolysis cells for high yield hydrogen gas production from organic matter. *Environmental science & technology, 42*(23), 8630-8640.

Lord, S. & Clay, J. (2006). Environmental impacts of oil palm–practical considerations in defining sustainability for impacts on the air, land and water. Paper presented at the International Planters Conference on Higher Productivity and Efficient Practices for Sustainable Agriculture, Putrajaya, Malaysia.

Luo, G., Xie, L., Zou, Z., Zhou, Q. & Wang, J.-Y. (2010). Fermentative hydrogen production from cassava stillage by mixed anaerobic microflora: effects of temperature and pH. *Applied energy, 87(12),* 3710-3717.

Malik, S. N., Pugalenthi, V., Vaidya, A. N., Ghosh, P. C. & Mudliar, S. N. (2014). Kinetics of nano-catalysed dark fermentative hydrogen production from distillery wastewater. *Energy Procedia, 54,* 417-430.

Mamimin, C., Jehlee, A., Saelor, S., Prasertsan, P. & Sompong, O. (2016). Thermophilic hydrogen production from co-fermentation of palm oil mill effluent and decanter cake by Thermoanaerobacterium thermosaccharolyticum PSU-2. *international journal of hydrogen energy, 41*(46), 21692-21701.

Mamimin, C., Singkhala, A., Kongjan, P., Suraraksa, B., Prasertsan, P., Imai, T. & Sompong, O. (2015). Two-stage thermophilic fermentation and mesophilic methanogen process for biohythane production from palm oil mill effluent. *international journal of hydrogen energy, 4*0(19), 6319-6328.

Manikkandan, T., Dhanasekar, R. & Thirumavalavan, K. (2009). Microbial production of Hydrogen from sugarcane Bagasse using Bacillus Sp. *Int J ChemTech Res, 1,* 344-348.

Maran, J. P., Manikandan, S., Thirugnanasambandham, K., Nivetha, C. V. & Dinesh, R. (2013). Box–Behnken design based statistical modeling for ultrasound-assisted extraction of corn silk polysaccharide. *Carbohydrate Polymers, 92*(1), 604-611.

Marañón, E., Castrillón, L., Quiroga, G., Fernández-Nava, Y., Gómez, L. & García, M. (2012). Co-digestion of cattle manure with food waste and sludge to increase biogas production. *Waste management, 32*(10), 1821-1825.

Masukawa, H., Sakurai, H., Hausinger, R. P. & Inoue, K. (2014). Sustained photobiological hydrogen production in the presence of N 2 by nitrogenase mutants of the heterocyst-forming cyanobacterium Anabaena. international journal of hydrogen energy, 39(34), 19444-19451.

McKinlay, J. B. (2014). Systems biology of photobiological hydrogen production by purple non-sulfur bacteria Microbial bioenergy: hydrogen production (pp. 155-176): Springer.

Meryemoğlu, B., Hasanoğlu, A., Kaya, B., Irmak, S. & Erbatur, O. (2014). Hydrogen production from aqueous-phase reforming of sorghum biomass: An application of the response surface methodology. *Renewable energy, 62,* 535-541.

Mielke, T. (2013). Global supply, demand and price outlook for palm and lauric oils. Paper presented at the 2nd palm oil Internet seminar.

Milciuviene, S., Milcius, D. & Praneviciene, B. (2006). Towards hydrogen economy in Lithuania. *international journal of hydrogen energy, 31*(7), 861-866.

Miyake, J., Miyake, M. & Asada, Y. (1999). Biotechnological hydrogen production: research for efficient light energy conversion. *Journal of Biotechnology, 70(1),* 89-101.

Mizuno, O., Dinsdale, R., Hawkes, F. R., Hawkes, D. L. & Noike, T. (2000). Enhancement of hydrogen production from glucose by nitrogen gas sparging. *Bioresource technology, 73*(1), 59-65.

Mody, V. V., Siwale, R., Singh, A. & Mody, H. R. (2010). Introduction to metallic nanoparticles. *Journal of Pharmacy and Bioallied Sciences, 2*(4), 282.

Mohan, S. V., Babu, V. L. & Sarma, P. (2008). Effect of various pretreatment methods on anaerobic mixed microflora to enhance biohydrogen production utilizing dairy wastewater as substrate. *Bioresource technology, 99*(1), 59-67.

Mohanraj, S., Anbalagan, K., Kodhaiyolii, S. & Pugalenthi, V. (2014). Comparative evaluation of fermentative hydrogen production using Enterobacter cloacae and mixed culture: Effect of Pd (II) ion and phytogenic palladium nanoparticles. *Journal of Biotechnology, 192*, 87-95.

Mohanraj, S., Anbalagan, K., Rajaguru, P. & Pugalenthi, V. (2016). Effects of phytogenic copper nanoparticles on fermentative hydrogen production by Enterobacter cloacae and Clostridium acetobutylicum. *International Journal of Hydrogen Energy, 41*(25), 10639-10645.

Mu, Y., Zheng, X.-J., Yu, H.-Q. & Zhu, R.-F. (2006). Biological hydrogen production by anaerobic sludge at various temperatures. *international journal of hydrogen energy, 31*(6), 780-785.

Mullai, P., Yogeswari, M. & Sridevi, K. (2013a). Optimisation and enhancement of biohydrogen production using nickel nanoparticles–a novel approach. *Bioresource Technology, 141*, 212-219.

Mullai, P., Yogeswari, M. & Sridevi, K. (2013b). Optimisation and enhancement of biohydrogen production using nickel nanoparticles–a novel approach. *Bioresour Technol, 141*, 212-219.

Myers, R. H., Montgomery, D. C. & Anderson-Cook, C. M. (2016). Response surface methodology: process and product optimization using designed experiments. John Wiley & Sons.

Nair, A. T., Makwana, A. R. & Ahammed, M. M. (2014). The use of response surface methodology for modelling and analysis of water and wastewater treatment processes: a review. *Water Science and Technology, 69*(3), 464-478.

Nandi, R. & Sengupta, S. (1998). Microbial production of hydrogen: an overview. *Critical reviews in microbiology, 24*(1), 61-84.

Nath, K., Kumar, A. & Das, D. (2005). Hydrogen production by Rhodobacter sphaeroides strain OU 001 using spent media of Enterobacter cloacae strain DM11. *Applied microbiology and biotechnology, 68*(4), 533-541.

Nawi, N. S. M., Deros, B. M., Rahman, M. N. A., Sukadarin, E. H. & Nordin, N. (2016). Malaysian oil palm workers are in pain: Hazards identification and ergonomics related problems. Malaysian Journal of Public Health Medicine, 1(Specialissue1), 1-8.

Neilan, B. A., Jacobs, D., Blackall, L. L., Hawkins, P. R., Cox, P. T. & Goodman, A. E. (1997). rRNA sequences and evolutionary relationships among toxic and nontoxic cyanobacteria of the genus Microcystis. *International Journal of Systematic and Evolutionary Microbiology, 47*(3), 693-697.

Niu, K., Zhang, X., Tan, W.-S. & Zhu, M.-L. (2010). Characteristics of fermentative hydrogen production with Klebsiella pneumoniae ECU-15 isolated from anaerobic sewage sludge. *International Journal of Hydrogen Energy, 35*(1), 71-80.

Oh, Y.-K., Seol, E.-H., Kim, J. R. & Park, S. (2003). Fermentative biohydrogen production by a new chemoheterotrophic bacterium Citrobacter sp. Y19. *International Journal of Hydrogen Energy, 28*(12), 1353-1359.

Ohimain, E. I. & Izah, S. C. (2017). A review of biogas production from palm oil mill effluents using different configurations of bioreactors. *Renewable and Sustainable Energy Reviews, 70*, 242-253.

Ohta, T. (2006). Some thoughts about the hydrogen civilization and the culture development. *international journal of hydrogen energy, 31*(2), 161-166.

Ong, H., Mahlia, T. & Masjuki, H. (2012). A review on energy pattern and policy for transportation sector in Malaysia. *Renewable and Sustainable Energy Reviews, 16*(1), 532-542.

Owen, W., Stuckey, D., Healy, J., Young, L. & McCarty, P. (1979). Bioassay for monitoring biochemical methane potential and anaerobic toxicity. *water research, 13*(6), 485-492.

Özgür, E., Afsar, N., de Vrije, T., Yücel, M., Gündüz, U., Claassen, P. A. & Eroglu, I. (2010a). Potential use of thermophilic dark fermentation effluents in photofermentative hydrogen production by Rhodobacter capsulatus. *Journal of cleaner production, 18*, S23-S28.

Özgür, E., Mars, A. E., Peksel, B., Louwerse, A., Yücel, M., Gündüz, U., Eroğlu, İ. (2010b). Biohydrogen production from beet molasses by sequential dark and photofermentation. *International Journal of Hydrogen Energy, 35*(2), 511-517.

Özkan, E., Uyar, B., Özgür, E., Yücel, M., Eroglu, I. & Gündüz, U. (2012). Photofermentative hydrogen production using dark fermentation effluent of sugar beet thick juice in outdoor conditions. *international journal of hydrogen energy, 37*(2), 2044-2049.

Patel, S. K., Kumar, P., Singh, M., Lee, J.-K. & Kalia, V. C. (2015). Integrative approach to produce hydrogen and polyhydroxybutyrate from biowaste using defined bacterial cultures. *Bioresource technology, 176,* 136-141.

Patel, S. K., Lee, J.-K. & Kalia, V. C. (2017). Nanoparticles in biological hydrogen production: an overview. *Indian journal of microbiology,* 1-11.

Perera, K. R. J., Ketheesan, B., Gadhamshetty, V. & Nirmalakhandan, N. (2010). Fermentative biohydrogen production: evaluation of net energy gain. *international journal of hydrogen energy, 35*(22), 12224-12233.

Peu, P., Béline, F. & Martinez, J. (2004). Volatile fatty acids analysis from pig slurry using high-performance liquid chromatography. *International Journal of Environmental Analytical Chemistry, 84*(13), 1017-1022.

Pilon, L. & Berberoğlu, H. (2014). Photobiological hydrogen production. CRC Press.

Qu, X., Alvarez, P. J. & Li, Q. (2013). Applications of nanotechnology in water and wastewater treatment. *water research, 47*(12), 3931-3946.

Rai, P. K., Singh, S. & Asthana, R. (2012). Biohydrogen production from cheese whey wastewater in a two-step anaerobic process. *Applied biochemistry and biotechnology, 167*(6), 1540-1549.

Rana, S., Singh, L., Wahid, Z. & Liu, H. (2017). A Recent Overview of Palm Oil Mill Effluent Management via Bioreactor Configurations. *Current Pollution Reports, 3*(4), 254-267.

Ranquet, C., Ollagnier-de-Choudens, S., Loiseau, L., Barras, F. & Fontecave, M. (2007). Cobalt Stress in Escherichia coli THE EFFECT ON THE IRON-SULFUR PROTEINS. *Journal of Biological Chemistry, 282*(42), 30442-30451.

Rasouli, M., Ajabshirchi, Y., Mousavi, S. M., Nosrati, M. & Yaghmaei, S. (2015). Process optimization and modeling of anaerobic digestion of cow manure for enhanced biogas yield in a mixed plug-flow reactor using response surface methodology. *Biosci Biotech R Asia, 12,* 2333-2344.

Rechtenbach, D. & Stegmann, R. (2009). Combined bio-hydrogen and methane production. Paper presented at the Proc. Sardinia 2009 Twelfth International Waste Management and Landfill Symposium.

Reijnders, L. & Huijbregts, M. (2008). Palm oil and the emission of carbon-based greenhouse gases. *Journal of cleaner production, 16*(4), 477-482.

Ren, N.-Q., Guo, W.-Q., Wang, X.-J., Xiang, W.-S., Liu, B.-F., Wang, X.-Z., Chen, Z.-B. (2008). Effects of different pretreatment methods on fermentation types and dominant bacteria for hydrogen production. *international journal of hydrogen energy, 33*(16), 4318-4324.

Reza, M. (2014). Measuring forest fragmentation in the protected area system of a rapidly developing Southeast Asian tropical region. Science Postprint, 1(1), e00030.

Rodionov, D. A., Hebbeln, P., Gelfand, M. S. & Eitinger, T. (2006). Comparative and functional genomic analysis of prokaryotic nickel and cobalt uptake transporters: evidence for a novel group of ATP-binding cassette transporters. *Journal of bacteriology, 188*(1), 317-327.

Roosta, M., Ghaedi, M. and Daneshfar, A. (2014). Optimisation of ultrasound-assisted reverse micelles dispersive liquid–liquid micro-extraction by Box–Behnken design for determination of acetoin in butter followed by high performance liquid chromatography. *Food chemistry, 161,* 120-126.

Rossi, D. M., Da Costa, J. B., De Souza, E. A., Peralba, M. d. C. R., Samios, D. & Ayub, M. A. Z. (2011). Comparison of different pretreatment methods for hydrogen production using environmental microbial consortia on residual glycerol from biodiesel. *international journal of hydrogen energy, 36*(8), 4814-4819.

Roy, S., Ghosh, S. & Das, D. (2012). Improvement of hydrogen production with thermophilic mixed culture from rice spent wash of distillery industry. *international journal of hydrogen energy, 37*(21), 15867-15874.

Sakurai, H., Masukawa, H., Kitashima, M. & Inoue, K. (2013). Photobiological hydrogen production: bioenergetics and challenges for its practical application. Journal of Photochemistry and Photobiology C: *Photochemistry Reviews, 17,* 1-25.

Sambrook, J. & Russell, D. W. (2001). Molecular cloning: a laboratory manual. third. Cold pring Harbor Laboratory Press, New York.

Schuchardt, F., Wulfert, K., Darnoko, D. & Herawan, T. (2008). Effect of new palm oil mill processes on the EFB and POME utilization. J Oil Palm Res (Spec Iss Oct 2008), 115-126.

Seengenyoung, J., Sompong, O. & Prasertsan, P. (2014). Comparison of ASBR and CSTR reactor for hydrogen production from palm oil mill effluent under thermophilic condition. *Advances in Bioscience and Biotechnology, 5*(03), 177.

Shin, J.-H., Yoon, J. H., Ahn, E. K., Kim, M.-S., Sim, S. J. & Park, T. H. (2007). Fermentative hydrogen production by the newly isolated Enterobacter asburiae SNU-1. *international journal of hydrogen energy, 32*(2), 192-199.

Singh, G., Growers' Council, M. O. P., Huan, L., Leng, T. & Kow, D. (1999). Oil palm and the environment: a Malaysian perspective.

Singh, L., Siddiqui, M. F., Ahmad, A., Rahim, M. H. A., Sakinah, M. & Wahid, Z. A. (2013). Application of polyethylene glycol immobilized Clostridium sp. LS2 for continuous hydrogen production from palm oil mill effluent in upflow anaerobic sludge blanket reactor. *Biochemical engineering journal, 70,* 158-165.

Singh, L. & Wahid, Z. A. (2015). Methods for enhancing bio-hydrogen production from biological process: a review. *Journal of Industrial and Engineering Chemistry, 21*, 70-80.

Singh, S., Sarma, P. M. & Lal, B. (2014). Biohydrogen production by Thermoanaerobacterium thermosaccharolyticum TERI S7 from oil reservoir flow pipeline. *international journal of hydrogen energy, 39*(9), 4206-4214.

Soga, M. & Gaston, K. J. (2016). Extinction of experience: the loss of human–nature interactions. *Frontiers in Ecology and the Environment*, *14*(2), 94-101.

Sompong, O., Prasertsan, P., Intrasungkha, N., Dhamwichukorn, S. & Birkeland, N.-K. (2007). Improvement of biohydrogen production and treatment efficiency on palm oil mill effluent with nutrient supplementation at thermophilic condition using an anaerobic sequencing batch reactor. *Enzyme and microbial technology, 41*(5), 583-590.

Song, Z.-X., Li, W.-W., Li, X.-H., Dai, Y., Peng, X.-X., Fan, Y.-T. & Hou, H.-W. (2013). Isolation and characterization of a new hydrogen-producing strain Bacillus sp. FS2011. *international journal of hydrogen energy, 38*(8), 3206-3212.

Spruit, C. J. P. (1958). Simultaneous photoproduction of hydrogen and oxygen by Chlorella. Veenman.

Strickland, L. (1929). The bacterial decomposition of formate. *Biochemical Journal, 23*, 1187.

Stupperich, E., Eisinger, H.-J. & Schurr, S. (1990). Corrinoids in anaerobic bacteria. *FEMS Microbiology Letters, 87*(3-4), 355-359.

Stupperich, E., Eisinger, H. J. & Krätler, B. (1989). Identification of phenolyl cobamide from the homoacetogenic bacterium Sporomusa ovata. *The FEBS Journal, 186*(3), 657-661.

Su, H., Cheng, J., Zhou, J., Song, W. & Cen, K. (2009). Improving hydrogen production from cassava starch by combination of dark and photo fermentation. international *journal of hydrogen energy, 34*(4), 1780-1786.

Taherdanak, M., Zilouei, H. & Karimi, K. (2015). Investigating the effects of iron and nickel nanoparticles on dark hydrogen fermentation from starch using central composite design. *international journal of hydrogen energy, 40*(38), 12956-12963.

Tao, Y., He, Y., Wu, Y., Liu, F., Li, X., Zong, W. & Zhou, Z. (2008). Characteristics of a new photosynthetic bacterial strain for hydrogen production and its application in wastewater treatment. *international journal of hydrogen energy, 33*(3), 963-973.

Teather, R. M. (1982). Maintenance of laboratory strains of obligately anaerobic rumen bacteria. *Applied and environmental microbiology, 44*(2), 499-501.

Thakur, V., Jadhav, S. & Tiwari, K. (2014). Optimization of different parameters for biohydrogen production by Klebsiella oxytoca ATCC 13182. *Trends in applied sciences research, 9*(5), 229.

Titirici, M.-M., Antonietti, M. & Thomas, A. (2006). A generalized synthesis of metal oxide hollow spheres using a hydrothermal approach. *Chemistry of Materials, 18*(16), 3808-3812.

Uyar, B., Eroglu, I., Yücel, M., Gündüz, U. & Türker, L. (2007). Effect of light intensity, wavelength and illumination protocol on hydrogen production in photobioreactors. *international journal of hydrogen energy, 32*(18), 4670-4677.

Valdez-Vazquez, I., Sparling, R., Risbey, D., Rinderknecht-Seijas, N. & Poggi-Varaldo, H. M. (2005). Hydrogen generation via anaerobic fermentation of paper mill wastes. *Bioresource technology, 96*(17), 1907-1913.

van der Werf, G. R., Dempewolf, J., Trigg, S. N., Randerson, J. T., Kasibhatla, P. S., Giglio, L., Collatz, G. (2008). Climate regulation of fire emissions and deforestation in equatorial Asia. Proceedings of the National Academy of Sciences, 105(51), 20350-20355.

Vijay, V., Pimm, S. L., Jenkins, C. N. & Smith, S. J. (2016). The impacts of oil palm on recent deforestation and biodiversity loss. *PloS one, 11*(7), e0159668.

Vijayaraghavan, K. & Ahmad, D. (2006). Biohydrogen generation from palm oil mill effluent using anaerobic contact filter. *international journal of hydrogen energy, 31*(10), 1284-1291.

Vogelgesang, F., Kumar, U. & Sundram, K. (2018). Building a sustainable future together: malaysian palm oil and european consumption. Journal of Oil Palm, Environment and Health (JOPEH), 9.

Wan, J., Jing, Y., Zhang, S., Angelidaki, I. & Luo, G. (2016). Mesophilic and thermophilic alkaline fermentation of waste activated sludge for hydrogen production: Focusing on homoacetogenesis. *water research, 102*, 524-532.

Wang, B., Wan, W. & Wang, J. (2009a). Effect of ammonia concentration on fermentative hydrogen production by mixed cultures. *Bioresource technology, 100*(3), 1211-1213.

Wang, G., Shen, X., Horvat, J., Wang, B., Liu, H., Wexler, D. & Yao, J. (2009b). Hydrothermal synthesis and optical, magnetic, and supercapacitance properties of nanoporous cobalt oxide nanorods. *The Journal of Physical Chemistry C, 113*(11), 4357-4361.

Wang, J. & Wan, W. (2008). Influence of Ni 2+ concentration on biohydrogen production. *Bioresource technology, 99*(18), 8864-8868.

Wang, Y.-Y., Ai, P., Hu, C.-X. & Zhang, Y.-L. (2011). Effects of various pretreatment methods of anaerobic mixed microflora on biohydrogen production and the fermentation pathway of glucose. *international journal of hydrogen energy, 36*(1), 390-396.

Winter, C.-J. (2005). Into the hydrogen energy economy—milestones. *international journal of hydrogen energy, 30*(7), 681-685.

Wu, S. Y., Hung, C. H., Lin, C. N., Chen, H. W., Lee, A. S. & Chang, J. S. (2006). Fermentative hydrogen production and bacterial community structure in high-rate anaerobic bioreactors containing silicone- immobilized and self-flocculated sludge. *Biotechnology and bioengineering*, *93*(5), 934-946.

Wu, T., Mohammad, A. W., Jahim, J. M. & Anuar, N. (2007). Palm oil mill effluent (POME) treatment and bioresources recovery using ultrafiltration membrane: effect of pressure on membrane fouling. Biochemical engineering journal, 35(3), 309-317.

Wu, T. Y., Mohammad, A. W., Jahim, J. M. & Anuar, N. (2009). A holistic approach to managing palm oil mill effluent (POME): Biotechnological advances in the sustainable reuse of POME. *Biotechnology advances*, *27*(1), 40-52.

Xie, Y., He, Y., Irwin, P. L., Jin, T. & Shi, X. (2011). Antibacterial activity and mechanism of action of zinc oxide nanoparticles against Campylobacter jejuni. *Applied and environmental microbiology*, *77*(7), 2325-2331.

Yang, H., Guo, L. & Liu, F. (2010). Enhanced bio-hydrogen production from corncob by a two-step process: dark-and photo-fermentation. *Bioresource technology, 101*(6), 2049-2052.

Yasin, N. H. M., Man, H. C., Yusoff, M. Z. M. & Hassan, M. A. (2011). Microbial characterization of hydrogen-producing bacteria in fermented food waste at different pH values. *international journal of hydrogen energy, 36*(16), 9571-9580.

Yilmaz, F., Balta, M. T. & Selbaş, R. (2016). A review of solar based hydrogen production methods. *Renewable and Sustainable Energy Reviews, 56*, 171-178.

Yin, Y. & Wang, J. (2016). Characterization and hydrogen production performance of a novel strain Enterococcus faecium INET2 isolated from gamma irradiated sludge. *international journal of hydrogen energy, 41*(48), 22793-22801.

Yokoi, H., Maki, R., Hirose, J. & Hayashi, S. (2002). Microbial production of hydrogen from starch-manufacturing wastes. *Biomass and bioenergy, 22*(5), 389-395.

Yokoi, H., Mori, S., Hirose, J., Hayashi, S. & Takasaki, Y. (1998a). H2 production from starch by a mixed culture of Clostridium butyricum and Rhodobacter sp. M [h] 19. *Biotechnology Letters, 20*(9), 895-899.

Yokoi, H., Saitsu, A., Uchida, H., Hirose, J., Hayashi, S. & Takasaki, Y. (2001). Microbial hydrogen production from sweet potato starch residue. *Journal of bioscience and bioengineering, 91*(1), 58-63.

okoi, H., Tokushige, T., Hirose, J., Hayashi, S. & Takasaki, Y. (1998b). H2 production from starch by a mixed culture of Clostridium butyricum and Enterobacter aerogenes. *Biotechnology Letters, 20*(2), 143-147.

Yossan, S., Sompong, O. & Prasertsan, P. (2012). Effect of initial pH, nutrients and temperature on hydrogen production from palm oil mill effluent using thermotolerant consortia and corresponding microbial communities. *international journal of hydrogen energy, 37*(18), 13806-13814.

Yusof, T. R. T., Man, H. C., Rahman, N. A. A. & Hafid, H. S. (2014). Optimization of Methane Gas Production From Co-Digestion of Food Waste and Poultry Manure Using Artificial Neural Network and Response Surface Methodology. *Journal of Agricultural Science, 6*(7), 27.

Zandvoort, M. H., van Hullebusch, E. D., Gieteling, J. & Lens, P. N. (2006). Granular sludge in full-scale anaerobic bioreactors: trace element content and deficiencies. *Enzyme and microbial technology, 39*(2), 337-346.

Zhang, C., Zhu, X., Liao, Q., Wang, Y., Li, J., Ding, Y. & Wang, H. (2010). Performance of a groove-type photobioreactor for hydrogen production by immobilized photosynthetic bacteria. *international journal of hydrogen energy, 35*(11), 5284-5292.

Zhang, M.-L., Fan, Y.-T., Xing, Y., Pan, C.-M., Zhang, G.-S. & Lay, J.-J. (2007a). Enhanced biohydrogen production from cornstalk wastes with acidification pretreatment by mixed anaerobic cultures. *Biomass and bioenergy, 31*(4), 250-254.

Zhang, Y. & Shen, J. (2007b). Enhancement effect of gold nanoparticles on biohydrogen production from artificial wastewater. *International Journal of Hydrogen Energy, 32*(1), 17-23.

Zhao, W., Zhang, Y., Du, B., Wei, D., Wei, Q. & Zhao, Y. (2013). Enhancement effect of silver nanoparticles on fermentative biohydrogen production using mixed bacteria. *Bioresource technology, 142*, 240-245.

Zhao, Y. & Chen, Y. (2011). Nano-TiO2 enhanced photofermentative hydrogen produced from the dark fermentation liquid of waste activated sludge. *Environmental science & technology, 45*(19), 8589-8595.

Zhu, H. & Béland, M. (2006). Evaluation of alternative methods of preparing hydrogen producing seeds from digested wastewater sludge. *International Journal of Hydrogen Energy, 31*(14), 1980-1988.

Zong, W., Yu, R., Zhang, P., Fan, M. & Zhou, Z. (2009). Efficient hydrogen gas production from cassava and food waste by a two-step process of dark fermentation and photo-fermentation. *Biomass and bioenergy, 33*(10), 1458-1463.